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The characteristics of atmospherics and associated thunderclouds : their magnitudes and variations

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Abstract : The present state of knowledge on the characteristics of atmospherics, its magnitudes under different seasonal and meteorological conditions as well as their variations depending on the activity of the sources including the propagation involved, is critically reviewed Emphasis is laid on the nature of atmospherics and its diurnal and seasonal variations besides the characteristic patterns achieved during disturbed weather conditions The physics of the frequency law and the associated radiation field are discussed at lengths In addition, the investigations on the characteristics of propagation are focussed The role of particle interactions in the development of electricity in thundercloud as well as the measurement of electric charge of cloud droplets and raindrops are pointed out Finally, the scopes of future works are outlined

Keywords : Atmospherics, source activity, thundercloud.

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Plan of the Article

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1. Introduction

The impulses of electromagnetic radiation generated by lightning discharges in thunderclouds cause the interference to radio receptions When the radiations from lightning flashes in thundercloud are received at a distance by a receiver tuned to a certain frequency with a specified bandwidth, the output in the receiver is called atmospheric radio noise. The location of the thunderstorm, its nature of growth and decay, the flash characteristics of the lightning discharge and the propagation conditions of the ionosphere are the main determining factors for the nature of atmospherics obtained. For the long-range navigational aids and for a World-wide frequency standard, extensive studies on radio wave propagation at low and very low frequencies are needed. For frequencies below 14.7 kHz, no transmitter is in continuous operation over long distances [1] except the OMEGA transmissions. But there is always a presence of atmospheric radio noise, which may be used for the purpose.

It is also observed that there are variations of field strength at very low frequencies due to solar UV, X-rays and high energy particles in the plasma of mesosphere and lower thermosphere *i.e.*, the D-region and the lower part of the E-layer [2] Hence the variation of field strength at very low frequency (VLF) may be used as a suitable indicator to study such effects on ionosphere. The theory of wave-guiding in the earth-ionosphere cavity can well interpret the propagation of electromagnetic wave from VLF to 100 kHz. This was observed by low frequency transmitter. But to observe the anomalous behaviour of the field strength during special geophysical events, the transmitter distances normally should not exceed 1500 km [3].

An excellent correlationship between atmospherics and lightning flashes has already been established [4–6]. According to Schonland [7], a complete lightning discharge is a flash, while a stroke is a partial discharge of low luminous intensity Thus a flash in the same or in an adjacent channel, may consists of a single stroke or multiple strokes [8] If the luminosity lasts for more than 40 m sec in the channel, it is called long-continuing luminosity A stroke followed by such luminosity is a long-continuing stroke. Similarly, the stroke followed by continuing luminosity of duration less than 40 m sec is known as a short continuing stroke. In a discrete stroke the luminosity decreases abruptly. It is observed that the electric field slowly changes during the interval of continuing luminosity [9] In a hybrid flash, there is one or more long continuing strokes while a discrete flash involves short continuing strokes or a discrete stroke [10].

2. Nature of atmospherics

In all types of lightning flashes, electrical discharges occur inside the cloud These discharges are responsible for the electromagnetic radiations giving rise to noise bursts at any frequency in the VLF, LF, MF and VHF bands. This noise interferes to radio reception and manifests itself as atmospherics when received at a distance. Thus, a lightning flash may be regarded as an impulse generator having energy components extending over a wide range of frequencies [11].

If the sources of discharge of the radiation exist within 300 km from the point of observation, then they are known as local sources The radiations from these sources come directly to the observation point. The days of local activity of a season are those days on which local sources are present. High amplitude noise burst are due to local sources [12]. Sources lying within 300 km and 1000 km are near sources. Radiations in MF and HF bands are expected to come to the receiving point from near sources by ionospheric reflection. Sources lying beyond 1000 km from the receiving station are called distant sources. Here also, radiations are received by means of ionospheric reflections Thus when the propagation conditions are favourable for any given frequency, signals from such sources can appear as noise in the receiver. Since there are large number of sources beyond 1000 km, a large number of noise bursts of varying amplitude can be received from different sources thus forming practically a continuous noise [13].

The noise arising from local sources is always in the form of distinct and well-separated noise burst. The noise bursts are also distinct when they are coming from the near sources. But if the active near sources are large at any time, the number of noise burst received is also large and it then appears to be continuous [14]. Extensive investigations reveal that distinct noise bursts appear over a background of continuous atmospheric radio noise and that atmospheric radio noise may be classified into three types [15].

The electromagnetic impulses generated from a lightning flash have a spectral distribution of power with a maximum around 10 kHz [16]. Each of the impulses lasts about 100 μ sec The peak power of a typical flash is near about 1000 kW at 10 kHz for 1 kHz band width. Schonland *et al* [17] found that lightning discharges are the sources of electromagnetic radiation which can propagate to a long distance by reflection in ionospheric layers and that the magnetic field plays a major role in the mechanism of reflection. It has been shown by the direction finding method that a great majority of sources lies in the region of definite meteorological disturbances, where very frequently thunderstorms are developed. These major sources lie in the regions usually associated with equatorial continental areas All thunderstorms within 6000 km of the receiving station are significant as possible sources of atmospherics [18]. Brooks [19] estimated that about 50,000 thunderstorms occur everyday throughout the globe and that on an average, about 2000 storms are in progress at any moment, corresponding to at least 100 multiple flashes per sec, the average duration being of the order of 250 m sec. The time interval between successive strokes of a multiple flash may be 10-500 m sec, the average value being 60 m sec [17]. A multiple flash consists of a pilot streamer carrying a current of few amperes, a stepped leader stroke carrying nearly 1000 amp current, a dart leader having about 1000 amp current and a return stroke carrying a current of high magnitude (10,000–100,000 amp with an average at 20,000 amp). The return strokes are long, contain huge currents and change slowly. These return strokes radiate maximum energy in the frequency range of 3–30 kHz with a peak at about 10 kHz. They may have continuing currents with energy in the ELF range [20]. Leader strokes have smaller but more rapidly varying components compared with the return strokes. Stepped leaders and junction processes radiate energy [21] at frequencies above 30 kHz. The general results show that each flash contains 1–42 'main' strokes and that each main stroke is preceded by a leader stroke. These leader strokes proceed downwards from the cloud. For most of the cases, the leader of the first main stroke proceeds in steps and shows considerable branching. The leader strokes are apprehended to be the effective sources of noise from 20 kHz to 1 MHz. At higher frequencies the noise assumes a quasi-continuous form possibly due to many discharges with small currents than either return stroke or K-changes, but involving more rapid changes [22]. Hence, neither K-changes nor the return strokes may be the possible sources of noise at higher frequencies. From the records of Malan [23], it seems that a mechanism other than K-changes or return stroke is involved for noise over the range of 100 kHz to 1 MHz. The propagation of each atmospheric noise component *viz.* ground waves and impulses reflecting from ionosphere under proper reflecting conditions, obeys the normal propagation laws of signal transmission. The result of multiple impulses received at a station is to increase the equivalent noise field.

The frequency spectra of atmospherics give information about the wave propagation propagation of atmospherics and the mechanisms of lightning discharges. Taylor and Jean [24] made an observation of the intensity of atmospherics at 1–40 kHz emitted from ground discharges at distances of 150–600 km. Watt and Maxwell [25] recorded the intensity at 1–100 kHz at distances of 30–50 km, Horner [22] at 11 MHz and 6 kHz at distances of 1.5–6.5 km, Takagi [26] at 100 kHz–500 MHz at 15–20 km, and Schaffer and Goodall [27] at 150 MHz at 1–32 km. These observations reveal that the characteristics of atmospherics which define their frequency spectra, depend on the configuration and development of thunderclouds. They found variations according to the seasonal and meteorological conditions as well as geographical features.

3. Diurnal and seasonal variations of atmospherics

The daily records of IFIA were analysed by different workers all over the world and the results were published in the literature. During the IGY period, scientists in different countries worked on the subject and noted the general variations of IFIA observed at different frequencies during a day. The World Meteorological Organisation [28] subdivided the diurnal variation of IFIA into the following features : **A** Sunrise effect, **B**–Last minimum, **C**–Recovery effect, **D**–Morning minimum, **E**–Afternoon maximum, **F**–Late minimum and **G**–Night maximum (Figure 1). The sunrise and sunset effects observed on very long waves were explained in terms of metallic and dielectric type of ionospheric reflection occurring in the day and night side of the ionosphere, respectively. Observation indicated that a sharp single or sometimes a double peak in the radio noise level occurs just before sunrise and just after sunset [29]. The diurnal characteristics of distant atmospherics were studied by Khastgir and Ray [30]. Chiplonkar and Karekar [31] explained the times of start and end of the sunrise fall at 27 kHz in Poona in terms of a single-hop reception from eastern and western sources lying within the geometrical optical horizon. The sunrise effect has been explained by them to be due to the absorption in the D-region of the ionosphere which is formed with the sunrise at the layer. Likewise, the night maxima which is the sunset effect, corresponds to the disappearance of the D-region from the propagation path [32]. Sen and Das Gupta [33] attempted to explain the sunrise effect at low frequencies in terms of a cosmic ray layer developing below the E-region, immediately after sunrise by the

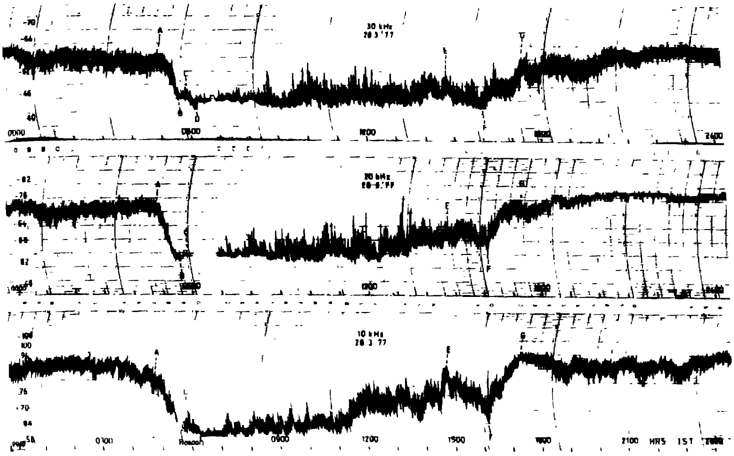

Figure 1. Photograph of typical records of integrated field intensity of atmospherics showing the regular variations The ordinates are in dB above 1 μV/m The observation was made over Calcutta at 10, 20 and 30 kHz

visible solar radiation. Lauter [34] analysed the atmospheric radio noise variations and concluded that the sunrise effect in the noise records is based upon geometrical-optical conditions and happens therefore very precisely everyday within a few minutes under normal conditions. As the noise propagates *via* E-region during night time, there are only very low propagation losses. But when the last reflection point on these several hop paths is coming in sunlight, then the noise level suddenly decreases. The explanation is that with the sunrays reaching lower ionosphere (90 km height) at a point 800–900 km westward to the observation site, photodetachment processes start. In these processes, negative ions eject electrons by absorption of visible sunlight having energy greater than electron affinity [35]

The stepwise amplitude minima with simultaneous phase advance was first investigated by Reiker [36]. Crombie and Rath [37] also observed the amplitude variations in the form of pronounced steps during sunrise in the recording of VLF signals. The stepped structure of the sunrise effect was tried by various workers to explain in terms of source distribution and changes in the state of ionisation in the propagation path due to the incidence of solar ionizing radiations. The regular amplitude variations of the signal strength during sunrise is due to the changes of the ionospheric reflection coefficients at sunrise at the ionospheric reflection points. Ries [38] who observed the periodic variation of field strength during sunrise on VLF signals propagated over long distance, tried to explain the steps by the waveguide mode theory. In case of VLF atmospherics however, radiation from such sources at long distances would be masked by the stronger fields due to nearer sources. Chiplonkar and Marwadi [35] attempted to explain the steps in atmospheric level in terms of a ray theory, valid for such near sources. Bhattacharya *et al* [39] invoked a similar ray concept with certain modifications. There are sources both towards east and west of any station on the earth's surfaces.

The integrated field intensity of atmospherics shows a seasonal variation. Field strength in day time has a tendency to attain minimum in winter while it is maximum in summer. The same behaviour of field strength is observed at night also. The high value of field intensity in summer is attributed to the greater source activity at such times in northern hemisphere. However, the summer to winter ratio of IFIA is highly dependent with the location as well as with frequency. Mainly the local meteorological condition determines the seasonal effect around the equatorial storm centres. This is evident from the fact that the level of atmospherics is exceptionally high in the monsoon period, while local thunderstorms during the premonsoon months in north-eastern part of India cause as unusually large IFIA [40] The seasonal variation decreases with increasing frequency, in general.

4. Frequency law

Burch and Bloemsma [41] considered the recorded waveform of atmospherics of distant origin similar to damped sinuous waves and applied Fourier analysis to such waves After summarising the results of theoretical analysis and experimental investigations of many workers, Thomas and Burgess [42] observed that the rms atmospheric radio noise field strengths (ARN-FS) from a single lightning flash available to a receiver of 10 kHz bandwidth is expressed in $\mu V/m$ by the relation .

$$E_0 = 36/rf^2 , \tag{1}$$

where, r = distance of the receiving point from the source in units of 1000 km and f = the frequency in MHz Alternatively, for any given bandwidth and all flashes taken collectively, we have

$$E_0 = A/rf^2 , \tag{2}$$

where A is a constant and r is also considered to be nearly constant for a given time block and season as sources are usually lacalized at such times. It was therefore, assumed that the ARN-FS is proportional to $1/f^2$, but the experimentally measured values due to different workers are not only widely different from these theoretical expectations but are also inconsistent and sometimes contradictory. The inverse square relation is not applicable under actual conditions mainly because that at most of the short wave frequencies, the ARN is affected by the propagation characteristics of the ionosphere and by the departures from the plane, perfectly conducting earth.

The duration of noise bursts, the amplitude of a noise bursts, the number of noise bursts and the time interval between successive noise bursts at a certain frequency follow the log-normal distribution [43]. It is found that the log-normal law is an approximate representation and not an accurate one. The accuracy realized is of the order of 90% which is of course, adequate for most engineering evaluations [44]. The lightning discharge is continuous throughout the activity of thunderclouds, though the flashes occurring are of different types [45]. Whenever thunder is heard there are about 10% ground strokes which is very small compared to the percentage found in temperate regions. The lifetime of a convection cell has a median value of about 30 min, similar to that reported from experiments in temperate zone. But the median duration of the life of an active thundercloud is about 3 hr which is very much higher than the values reported from temperate regions [46]. The radiation of electromagnetic energy is more or less a continuous process for the whole of a lightning discharge with a duration commonly in the range 0 1–1 sec.

5. Propagation characteristics

The characteristics of atmospheric propagation are governed by many factors, such as conductivity of the earth's surface, height and ionization of the lower ionosphere, direction of propagation *etc* In the 3–30 km range, the field is the vector sum of the static, induction and radiation components which change with the distance d approximately as $1/d^3$, $1/d^2$ and $1/d$ respectively. At a distance of about one-sixth wavelength, the amplitudes of the static and radiation components are approximately equal. At distances less than one wavelength, the static and induction terms still influence the total field The intensity of the ground wave component is inversely proportional to distance times an attenuation factor which is a function of surface conductivity The attenuation is lower for propagation paths of higher conductivity [47]. The vertical electric field of the skywave is variable. The effects due to meteors, solar flares, magnetic storms *etc.* are not well understood. However, it may be said that the reflection coefficients on a summer day and night are of the order of 0 3 and 0.5 respectively, around 20 kHz. Reflection coefficients during winter are found to be little higher. Besides the vertical electric field, there are also the horizontal electric field the vertical magnetic field and the horizontal magnetic field with their corresponding reflection terms. The complex reflection coefficients and the conversion terms [48] produce a polarization of the reflected skywave which is different in comparison to the incident skywave. The times of arrival of the skywaves are functions of the propagation distance and the ionosphere reflection height. Atmospheric waveforms are in general, explained in terms of individual pulses arriving *via* ground and skywave. Waveforms recorded close to the source, reveal these individual pulses relatively clearly. Usually, the waveguide mode propagation characteristics are referred to in terms of attenuation rates and phase velocities. In the band of frequencies 10–30 kHz, the attenuation rates [49] vary from 1 dB to 4 5 dB/1000 km. The various parameters affecting propagation, are responsible for this variation in attenuation. Attenuation over land paths is about 1.0 dB/1000 km greater than over sea paths [50]. There are basically two methods of determining the spectrum of an atmospheric. In the first method, a wide band receiver is utilized for recording and then the resulting waveform is subjected to Fourier analysis. In the second method, parts of the spectrum are sampled by narrow band receivers. The first one can yield a continuous spectrum and is also capable of giving information on the relative phase as well as the amplitude. However, it demands much computation and there may be interference from stations. The second one is preferred more, particularly at higher frequencies, where station interference is serious.

The noise data required for different communication services have been furnished for the whole land mass of India through a set of three data sheets and a map of India showing the days of local activity in different regions in the four different seasons. Atmospheric noise in India consists of noise bursts arising from the local or nearer sources. The other interference due to distant sources contribute to a background which has been evaluated and furnished [51]. VHF noise radiation due to lightning flashes can travel to distances of the order of 500 km *via* the sporadic E-layer or by troposcatter. This is estimated to give rise to continuous noise of the order of 0.1 $\mu V/m$ at 100 MHz and 1 kHz pass band [52].

6. Requirements of thunderstorms generation mechanism

It is now wellknown that atmospherics originating in lightning discharges are closely associated with the thunderclouds developed. It is assumed that the thunderstorm is essentially the same phenomenon wherever it is found and therefore, the observations listed below from a mutually consistent set of requirements must be met by any complete explanation of the generation of charge and lightning in thunderstorms.

(i) A charge of 40 Coulombs, according to Malan [53] is essential to supply the first lightning flash within 5–30 min of the appearance of precipitation particles of radar detectable size.

(ii) The onset of strong electrification at some level, follows the appearance of frozen particles [54]. In general, magnitudes of fields in clouds containing solid particles are 10–100 times those in all-water clouds.

(iii) The charge generation and separation processes are closely related to vertical convection and development of precipitation [55].

(iv) In a thundercloud, there is usually a net positive charge in the upper portion and net negative charge in the lower portion. A third region of net positive charge sometimes appears at the base of the clouds in the central core of the precipitation. In a thunderstorm, the charge on precipitation particles is mainly positive in the upper layers, a mixture of charges in the intermediate levels, and negative on the average in the lower levels. There is a strong tendency for charge of the negative sign to be associated with the larger precipitation particles [56].

(v) A complete explanation [57] of thunderstorm electrification should allow for the electrification of clouds with temperatures entirely above 0°C.

6.1 Development of electricity in thundercloud

The thundercloud is the main source of energy for other atmospheric electrical phenomena Yet there is no satisfactory understanding of the relative importance of the various mechanisms to cause the cloud electrified. Nevertheless, a wealth of information about thunderstorms has been achieved by field observations The thundercloud begins with the formation of a cumulus cloud. It is formed when buoyant, warm, moist air rises in an updraft and cools by adiabatic expansion The electric fields within and about the cloud are seldom more than a few hundred volts per meter They arise from the superposition of the usual fair-weather electric field produced by the positive space charge in the environmental atmosphere and the enriched positive space charge in the surface layer of air

After one cloud has become electrified, other similarly electrified clouds may develop in the neighbourhood These produce additional CG flashes and external currents of the same polarity Sometimes aggregations of such clouds move across the country for many hours, continuing to produce primarily, if not exclusively, negative CG lightning This predominance of negative flashes to ground is reflected in the records of the National Lightning Detecting Network, which show that of the ten million annual CG flashes over the United States, about 95% are of negative polarity [58] The exceptional half million flashes that bring positive charge to ground annually, have two origins Many are produced by the usual storms that give flashes of both polarities After electrification has begun in a single cell and other cells have formed and become electrified the cloud system may become quite complicated Lines and clusters of active storms may form, sometimes dividing, sometimes merging, and at other times disappearing

A survey of literature [59,60] shows that the present state of knowledge are as follows

(i) Lightning is caused by a charge separation process that takes place within the cloud The dominant charge separation process responsible for lightning, is produced within the cloud by collisions between large and small ice particles. By this mechanism, charge of one sign is transferred to the larger particles and an equal and opposite charge to the smaller ones The electrical energy responsible for lightning is derived from the fall of charged precipitation particles under the influence of gravity.

(ii) The negative charge residing on the surface of the earth in fair weather is the result of the action of the many thunderstorms continuously in progress over the earth. Fair-weather electrical phenomena have no significant influence on thunderstorm electrification or on other meteorological phenomena Except for the chemical effects produced by lightning, thunderstorm electricity is without significant influence on processes taking place in the lower atmosphere The effect of lightning is to neutralize the charged particles responsible for the electrification of the cloud.

6.2 Measurement of electric charge of cloud droplets :

The intrinsic source of interest is the fact that particles in the cloud have a tremendously higher charge than the equilibrium charge calculated by Boltzmann's distribution This distribution law for instance, suggests that 90% of drops 1 mm in diameter carry a charge of less than 200 electrons [61] But raindrops of this size carry 100 times as many electrons in the warm cloud and 100,000 times as many in the thundercloud Furthermore, an asymmetric particle charge distribution is usual in the cloud Naturally, one is led to the question of the charge generation mechanism of such particles and to the thunderstorm charging mechanism In an early application of this method to cloud particles, Philips and Kinzer [62] captured the cloud droplets in a moistened settling chamber. Cloud droplets fell by gravity between vertical plane electrodes, where they were subjected to a horizontal electric field periodically reversed in direction Philips and Kinzer analyzed their data by using a scale of one-electron units

This method has been used widely in particle charge-size measurements Rosenblum [63] used this method to study the electric charge of dust particles Twomey [64] applied voltage in a manner that resulted in a charge droplet's tracing out an asymmetrical 'Zigzag' path. He placed the cylinder outdoors and photographed the trajectories of the freely falling droplets without a microscope. He was able to assume that the droplets fall at terminal velocity and thus calculated the size of the charged droplets The minimum detectable charge is a function of the size and electric charge of the droplet when the droplet diameter is 10 μ, the minimum detectable charge is 10 electrons

Magono and Kikuchi [65] used an ac field superposed on a dc field They drew air into the cylinder and photographed the paths of the particles, determining the size of the particles by the width of their traces in the photographs and their electric charge by the deflection of the traces under the electric field In this method, with air drawn forcibly into the cylinder, particle size cannot be determined from falling distance, as it can be when particles fall freely at terminal velocity The accuracy of size measurement is poor, here that of the electric charge measurement is also poor The minimum detectable charge is more than 50 electrons when drop diameter is 10 μ A similar method using only the dc field was used by Petrov [66] Sergieva [67] attached a plate covered with a mixture of transformer oil and vaseline to the electrodes and examined the traces on the plate. Colgate and Romero [68] estimated the size of droplets 5–20% in diameter by the degree of deflection due to sound waves Again, the accuracy with which particle size can be measured determines the accuracy of the electric charge measurements For a 10 μ droplet, the minimum detectable charge is over 100 electrons

To measure the net charge of droplets as a group, Wigand [69] used two plates High voltage was applied to the upper plate. The electric charge collected on the lower plate was measured by Wulf's electrometer Webb and Gunn [70] used a centrifuge technique to distinguish the cloud droplet group and the ion group. Pudovkina and Katsyka [71] collected charge on a plate in a cylinder. Because of electric leakage, water splashing effects, and other conditions, these observations are useful only in determining the predominant electric sign while Takahashi [72] developed an impactor method. The electric charge of droplets of different size groups is measured by using the cascade impactor. The collection efficiency of particles on the plate is that given by Rang and Wong [73]. Proctor [74] has succeeded in determining the size of particles in the cloud droplet range by a gas laser method. The mean electric charges of different drop sizes are shown in Figure 2.

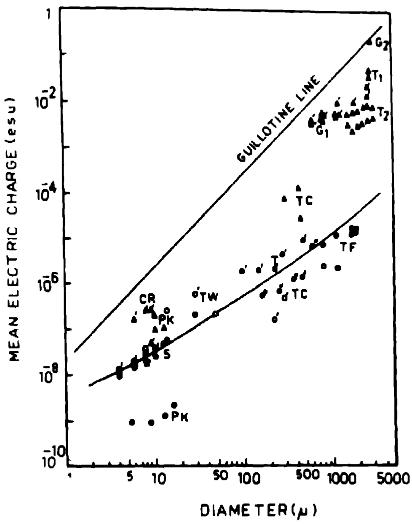

Figure 2. Mean electric charge of drops. Solid circles represent warm cloud case with negative charge, open circles for warm cloud case with positive charge, solid triangles for thunderstorm case with negative charge, open triangles for thunderstorm case with positive charge. PK represents data from Philips and Kinzer [76], S-Sergieva [77], CR-Colgate and Romero [78], TW Twomey [64], TC-Takahashi and Craig [79], T-Takahashi [72], TF-Takahashi and Fullerton [80], G1-Gunn [81], G2-Gunn [82], T1-Takahashi [83], T2-Takahashi [84]. Solid line is for the theoretical curve based on ion drop interaction

The guillotine line indicates the maximum charge attainable by a drop of given size. For this calculation, an electric field of 3400 V/cm was assumed, which is double the highest electric field reported in a thunderstorm. In drawing the Guillotine line, it was assumed that lightning starts at this electric field and that discharges from particles also begin at the same field. The other line in the figure is the calculated value based on ion-particle process in warm clouds.

7. Discussion and conclusions

Here are a few examples of worthwhile research activities that might be initiated to supplement those already in progress.

Grenet [75] suggested that the current flowing between the upper atmosphere and the cloud might be important in the production of the electrified cloud particles responsible for lightning. These electrified cloud particles were then carried to the lower part of the cloud by downdrafts, where they accumulated to form the lower region of negative charge. Theories of this kind may be tested by dropping chaff on the cloud top and seeing by radar if it is carried to lower levels by downdrafts.

The frequency spectra from ELF to UHF should be determined at various geographical locations at different distances from the source under all meteorological and seasonal conditions. These will help mainly to study the mechanism of lightning discharges, nature of wave propagation, the properties of whistlers *etc*. With more experimental data available, it will be possible to compare different models of ionosphere.

Solar flare and a high altitude nuclear detonation cause sudden enhancement of atmospherics. But peak occurs at different frequency for the two different cases. A peak around 27 kHz is observed in case of solar flare, while high altitude nuclear detonation causes a peak at about 120 kHz. The height gradient of electron density in the D-region may be different in the two cases, and may cause the shift of the peak. Further studies in this direction would be important, since they may provide a successful method of detection of a high altitude nuclear detonation from a long distance. The influence of solar activity on IFIA is not yet clearly explained. A further investigation in this direction will be informative.

There are certain features in the diurnal variation of IFIA which can not be explained in terms of the variation of either of the source activity or of propagation or of both. One such feature is the duration of sunrise effect in VLF and LF ranges and its frequency dependence. To explain such effects, further investigations are needed. The unusually large enhancement of the diurnal pattern of IFIA due to local meteorological disturbances may be an aid to the weather forecasting provided directional studies of atmospherics are made. The seasonal variation of IFIA is dominated by local meteorological conditions. It is rather difficult to ascertain any seasonal variation of propagation because of the wide variation of the activity of sources in different seasons. However, the seasonal variation may be used to ascertain the meteorological conditions in the neighbourhood of the observing station.

There is no clear conception of the method of charge accumulation in clouds or of the transfer of mechanism of mechanical and thermal energy to electrical energy. To solve the various problems related to atmospheric phenomenon, a greater understanding of the internal structure of the cloud in terms of mechanical, thermal and electrical energies is needed. The relationship between mechanical and electrical energy in various types of storms is to be explored.

Electric field measurements are to be made above clouds giving predominantly positive CG lightning to find if they have dipoles of inverted polarity. Experiment is to be properly planned to examine electric charge carried on falling precipitation particles using Doppler radars capable of more accurately measuring changes in fall speed after lightning. There is a need to develop improved balloon-brone instrumentation that is unaffected by strong ambient electric fields to be used for measuring the charge carried by individual falling precipitation particles. It will also help to determine how lightning may be accelerating the formation of rain and hail by using interferometers to determine the location of lightning in the cloud, and fast-scanning, high-resolution radar to observe the growth of the precipitation particles. We have to make measurements under maritime thundrclouds to find the electric field intensities required to produce point discharge from the water surface under different wave and sea surface conditions. Also we have to calculate the conduction currents over the tops of maritime storms and hurricanes to see how they compare with those over land storms, where the point discharge conditions beneath are quite different.

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